Chapter 2.4 TWENTY-YEAR TREND ANALYSES OF WATER QUALITY VARIABLES – 1985-2004

Central to evaluating the quality of the Commonwealth's surface waters are efforts to detect changing conditions over time. The most often asked question can be simply stated as: "Is the water getting better or worse?" Implicit in this fundamental question is the comparison of water quality during some period in the past with today's conditions.

Analysis of mid- to long-term water quality monitoring data is used to answer this question. Trend analysis, as presented in this report, more specifically answers the broader question by the application of an established statistical methodology. The evaluation of changes in the values of specific water quality variables, at fixed sample locations over a set period of time, is presented here as trend analysis. Summarizing these statistical results by major river basin provides a geographically interpretive answer to the simpler question.

The Water Quality Monitoring, Restoration, and Information Act (WQMIRA), § 62.1-44.19:5 of the Code of Virginia, directs the Department of Environmental Quality (DEQ) to…"determine water quality trends within specific and easily identifiable, geographically defined water segments." Furthermore, Section D of the Act specifies that reporting of those trends in the 303(d) and 305(b) Reports… "shall be developed in consultation with scientists from state universities prior to its submission by the Board to the United States Environmental Protection Agency" …and should… "indicate water quality trends for specific and easily identifiable geographically defined water segments and provide summaries of the trends as well as available data and evaluations so that citizens of the Commonwealth can easily interpret and understand the conditions of the geographically defined water segments."

To fulfill the requirements of WQMIRA, DEQ consulted with and contracted Carl Zipper, Ph.D., and Golde Holtzman, Ph.D., of Virginia Tech to select an appropriate statistical method and develop computer software for the detection and evaluation of water quality trends. The first generation of trend analyses, generated by the computer program WQ2, was reported in the 2002 and 2004 305(b) Reports[1]. The second generation methodology, referred to as WQ3, has been employed to generate the trend results in this report. WQ3 contains efficiency enhancements that allow a more flexible definition of seasonal duration and provide the capability for batch analyses of multiple stations and variables. The statistical procedures applied in WQ3 remain fundamentally unchanged from previous versions. In the following section, the additional WQMIRA requirements related to reporting, geographic summaries and interpretation are provided to facilitate the evaluation of water quality changes over time.

Detecting significant long-term trends requires datasets encompassing longer time periods than are traditionally considered in the 305(b) assessment process, which typically covers only the most recent five years of monitoring. Furthermore, because of the seasonal variability of water quality parameters, monitoring frequency and analytical methods must consider variations in measurements among the various seasons of the year. The Virginia DEQ began monitoring the Commonwealth's water quality even before the advent of the Clean Water Act in 1972. Data records at many water quality trend stations span 30 years or more of monitoring. Currently, DEQ operates a trend station network of 406 permanent monitoring stations where monthly or bimonthly data are collected on a variety of key water quality parameters. These fixed stations are located along, at or near the mouths, and often on the fall line of major rivers, near flow gauging stations where available, at key non-tidal and tidal stations in the Chesapeake Bay watershed, and in other areas of special interest. The total time period of interest in the analyses described in this report included the twenty calendar years from 1985 through 2004.

The parameters measured at each location vary slightly, depending on whether the station is located in a free-flowing freshwater stream, reservoir, or estuary. The core parameters measured are listed in Table 2.4-1, below. The subset of parameters selected for trend analysis is more limited for several reasons. Some of the parameters in the table are components of others, which were analyzed for trend, or they are utilized simply to evaluate, qualify or calculate the values of other parameters. In other cases, a parameter may have incomplete records and insufficient numbers of observations (too few data points) to calculate trends during the period of interest. For example, with the adoption of new Water

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[1] Final 2004 305(b)/303(d) Water Quality Assessment Integrated Report
http://www.deq.virginia.gov/wqa/ir2004.html

Quality Standards for *Escherichia coli* and *Enterococci* bacteria, monitoring for these parameters only began in 2000. Even though Water Quality Standards for fecal *coliform* bacteria will be phased out by 2008, fecal *coliform* monitoring results are still important because of lengthy records dating back to the late 1960's. Trend analyses for *E. coli* and *Enterococci* bacteria concentrations will complement those for fecal coliform bacteria, once long enough data records become available.

STORET PARAMETER CODE	DESCRIPTION	TREND VARIABLE
00010	TEMPERATURE, WATER (DEGREES CENTIGRADE)	Temperature (TEMP)
00025	BAROMETRIC PRESSURE (MM OF HG)	
00064	DEPTH OF STREAM, MEAN (FT)	
00076	TURBIDITY,HACH TURBIDIMETER (FORMAZIN TURB UNIT)	
00078	TRANSPARENCY, SECCHI DISC (METERS)	
00094	SPECIFIC CONDUCTANCE,FIELD (UMHOS/CM @ 25C)	
00095	SPECIFIC CONDUCTANCE (UMHOS/CM @ 25C)	
00096	SALINITY AT 25 DEGREES C (MG/ML)	
00299	OXYGEN ,DISSOLVED, ANALYSIS BY PROBE MG/L	Dissolved Oxygen converted to %Saturation (DO)
00400	PH (STANDARD UNITS)	pH
00410	ALKALINITY, TOTAL (MG/L AS CACO3)	
00500	RESIDUE, TOTAL (MG/L)	
00505	RESIDUE, TOTAL VOLATILE (MG/L)	
00510	RESIDUE, TOTAL FIXED (MG/L)	
00530	RESIDUE, TOTAL NONFILTRABLE (MG/L)	Total Suspended Solids (TSS)
00535	RESIDUE, VOLATILE NONFILTRABLE (MG/L)	
00540	RESIDUE, FIXED NONFILTRABLE (MG/L)	
00600	NITROGEN, TOTAL (MG/L AS N)	Nitrogen (TN)
00610	NITROGEN, AMMONIA, TOTAL (MG/L AS N)	
00625	NITROGEN, KJELDAHL, TOTAL, (MG/L AS N)	Total Kjeldahl Nitrogen (TKN)
00630	NITRITE PLUS NITRATE, TOTAL 1 DET. (MG/L AS N)	Nitrogen Oxidized (NOX)
00665	PHOSPHORUS, TOTAL (MG/L AS P)	Phosphorus (TP)
00680	CARBON, TOTAL ORGANIC (MG/L AS C)	
00900	HARDNESS, TOTAL (MG/L AS CACO3)	
00940	CHLORIDE,TOTAL IN WATER MG/L	
00945	SULFATE, TOTAL (MG/L AS SO4)	
31615	FECAL COLIFORM,MPN,EC MED,44.5C (TUBE 31614)	Bacteria (BACT)
31616	FECAL COLIFORM,MEMBR FILTER,M-FC BROTH,44.5 C	Bacteria (BACT)
31648	E. COLI - MTEC-MF N0/100ML	
31649	ENTEROCOCCI- ME-MF N0/100ML	
32211	CHLOROPHYLL-A UG/L SPECTROPHOTOMETRIC ACID. METH.	
46570	HARDNESS, CA MG CALCULATED (MG/L AS CACO3)	
49573	CARBON ORGANIC, FIELD FILTERED, DISSOLVED,WTR MG/L	
70507	PHOSPHORUS,IN TOTAL ORTHOPHOSPHATE (MG/L AS P)	
82079	TURBIDITY,LAB NEPHELOMETRIC TURBIDITY UNITS, NTU	

Table 2.4-1. Water quality parameters measured monthly or bimonthly by the Virginia Department of Environmental Quality at permanently established trend stations. "Trend variables" are parameters for which trend analyses were performed.

Of the various water quality parameters routinely collected at these stations, the subset of nine that were used for the current trend analyses include:

(1) Bacteria (Fecal Coliform – FC or BACT, combination of 31615 and 31616), *
(2) Dissolved Oxygen- expressed as DO % Saturation,
(3) Total Nitrogen - TN, *
(4) Oxidized Nitrogen (nitrate plus nitrite = NOX),
(5) Total Kjeldahl Nitrogen (organic nitrogen plus ammonia = TKN),
(6) Total Phosphorus - TP, *
(7) Acidity or pH - PH,
(8) Water Temperature - TEMP, and
(9) Total Suspended Solids - TSS.*

Variables in this subset are identified as 'TREND VARIABLES' in Table 2.4-1.

Of the nine variables analyzed, four (BACT, TN, TP, and TSS, as indicated by asterisks in the list) are considered key variables because of their utility for interpreting the desirability of water quality changes. For each of these four variables, a negative trend (decreasing concentration) unequivocally indicates a desirable change in ambient water quality. Elevated concentrations of these four key parameters are the most common causes of water quality deterioration or impairment. They are clear indicators of improving or deteriorating conditions, based solely on the direction of changes in their concentrations.

The desirable direction of change for the other five (supplemental) parameters is subject to interpretation. For example, a decrease in dissolved oxygen may at first seem to indicate deteriorating water quality. However, if the decreasing DO is a result of decreasing nutrients concentrations, this may be interpreted as a desirable trend (see Figure 2.4-5, later in this chapter). In the case of two specific nitrogen species considered, NOX and TKN, a trend may merely indicate a shift from one form of nitrogen to another rather than a change in total nitrogen concentration over time. In the case of pH, values at either extreme of the scale (exceedingly acidic or basic) are undesirable. Shifts in pH from either extreme toward more moderate values (either a positive or a negative trend) may be considered desirable, depending on local conditions. Significant temperature trends in either direction from historic values can have ecological significance on the distribution and abundance of aquatic organisms, because aquatic communities have adapted to prevalent climatic conditions over millennia. These concepts are discussed more fully for each parameter in the section on Summarizing and Evaluating Site Specific and Regional Trends.

The Seasonal Kendall Trend Analysis Method

Seasonal Kendall analysis is a common technique for detecting water quality trends, and studies utilizing seasonal Kendall analysis are found in numerous peer-reviewed scientific publications. For further information on the technique, readers may consult Hirsch et al. (1982)[2], Hirsch et al. (1991)[3], or Helsel and Hirsch (1992)[4].

The modified seasonal Kendall method, as implemented in the WQ3 software, is used to detect monotonic[5] trends in water quality over a period of time. Kendall's *Tau* is a rank-order statistic. The WQ3 software calculates the value of a numeric trend indicator, *Tau*, by determining the direction of change from each measured value of a water quality variable in the time series to the values of all subsequent measurements from the same season. The comparison begins with the first measurement (the oldest record) in a season, and is made sequentially with all subsequent values in time for the same season. Next, the second oldest value in time is compared in the same manner to all subsequent records in the same season. This comparison repeats until all pairs of values in the data set that occur within the same season have been compared sequentially. The seasonal trends thus characterized are subsequently integrated into a single collective trend. Because of the seasonal nature of water quality variables and the frequency at which the data were collected, the monitoring data were analyzed in blocks of twelve (monthly) seasons. January values were only compared to January values, February values with February values, and so forth for each of the twelve months.

It is well known that many water qualify variables tend to vary seasonally. Water quality nutrient concentrations, for example, are influenced by agricultural practices that vary seasonally. Similarly, streamflow influences many water quality parameters, and streamflow varies with seasons. Consequently, the seasonal Kendall test compares each water-quality value only with values that occur within the same season of subsequent years. In our application of seasonal Kendall analysis, we have elected to define "seasons" as months of the year, because many data series being analyzed include monthly water quality measurements.

Because the comparisons of measured values are qualitative and only determine the direction of changes, without regard to the magnitudes of the differences in values, the statistical test is considered to be very robust. That

[2] Hirsch, R.M., J. Slack, and R. Smith. 1982. Techniques of trend analysis for monthly water-quality data. Water Resources Research 18:107-121.
[3] Hirsch, R.M., R.B. Alexander, and R.A. Smith. 1991. Selection of methods for the detection and estimation of trends in water quality. Water Resources Research 27(5):803-813.
[4] Helsel, D.H., and R.M. Hirsch. 1992. Statistical Methods in Water Resources. Elsevier Science Publishers, Amsterdam. 529 pp.
[5] A monotonic trend is a trend that is predominantly unidirectional. It may be linear, smoothly curved, or irregular in form. The Kendall *Tau* method will not identify trends that reverse their predominant direction during the period of interest.

is, its results are not unduly affected by extreme values, errors, or outliers. The analysis is also appropriate for use in data sets that have 'censored' upper and lower limits of analytical detection. For example, the variable for bacteria contains values that are recorded as less than 100 (<100), which means that the actual value lies between 0 and 99. This value (100) is defined as the lower limit of detection. Bacteria values may also be censored at the upper limit, being recorded as greater than 8000 (>8000), which means that the value could be anywhere from 8001 to infinity. All censored values at the same limit are considered to be tied and they can still be qualitatively compared with one another, with quantified values within the defined range of detection, or with censored values at the other end of the scale.

Kendall's *Tau*, which may vary in value from -1.000 to +1.000, is a measure of the direction and relative uniformity (monotonicity) of the trend. The more consistent the trend is, the stronger the *Tau* value will be (*i.e.*, the further it will be from 0.000). Negative values of *Tau* indicate declining trends and positive values indicate increasing trends. The *Tau* value, however, does not indicate the magnitude of the trend. For instance, the dissolved oxygen (DO) values of 9.9, 9.8, 9.7, 9.6, and 9.5 mg/L would have a Tau value of –1.000, since each value is less than all previous values; however, so would a trend of 9, 7, 6, 4, 1, which is a much more severe trend. The *Tau* value indicates the consistency directional change, not the magnitude or rate of change. Another characteristic of the method is that changes in trend direction over time (*e.g.*, increasing trend for 10 years, followed by a decreasing trend for 10 years) may cancel out such that a trend over the full time period cannot be detected.

In addition to the *Tau* statistic, WQ3 calculates the significance of the trend as a 'P-value.' The P-value is the probability of observing an equal or more extreme value of *Tau* than that calculated from the data, if no real trend were present. The smaller the P-value, the more confidence we have in rejecting the 'null hypothesis' (H_o) that no real trend is present (H_0: *Tau* = 0.000). A P-value ≤ 0.05 (≤ 5%) would indicate that we would have a confidence of at least 95% in rejecting H_0 (Confidence = 100% - P %), and is generally interpreted to indicate statistical significance. In other words, we would have a 95% confidence that a real trend is present.

WQ3 calculates two distinct P-values, an independent P-value (PVALUE) and a dependent P-value (PVALCOVS). The independent p-value is calculated under the assumption that all measured values of a specific water quality variable are completely independent of one another, while the dependent P-value includes the assumption that the water quality observations for individual months or blocks are similar in value to those of the preceding and following months. For example, the water quality in January is assumed to be similar to the water quality in December and in February. When blocking seasonal data into twelve months, the dependent p value is often a better estimate of the significance of the trend6.

When WQ3 detects a significant trend, it also estimates a linear regression equation that can be used to characterize the observed water quality changes. This output includes estimators for a slope and a y-intercept (value of the variable when time = 0.0). The slope estimate is defined as the 'median' rate of change in value of the water quality parameter per year. An advantage of the linear regression output is that the slope and intercept estimators can then be used to estimate future water quality values for those variables with statistically significant trends. Several considerations are of importance when applying the linear regression projections: (1) the assumption that the trend will remain constant may not be valid - there is always a risk of error when regressions are projected beyond the limits of the observations that went into their estimation, and water quality management changes may cause future patterns of water quality change to vary from those of the past (2) the assumption that the trend is linear may not be valid, and (3) the projected line represents the median point of the prediction and there is no confidence interval associated with the estimate; consequently, the point of intersection with a specified criterion or standard would represent a 50% violation rate.

In the current study, whenever significant trends were observed for those variables that have water quality standards or screening values, the trends were projected to the year 2008. When the predicted values violated current water quality standards or screening values, the corresponding water body segment was assigned to the assessment category of 5A (the assessment unit is threatened and a TMDL is needed) or 2B (waters are of concern to the state), respectively. By identifying the possibility of future impairment, DEQ can proactively target waters of concern for additional studies or for possible implementation of mitigation measures.

It should be noted that with the Kendall *Tau* method a situation can occur where the *Tau* value indicates that a significant trend is present, but the estimated slope is still zero. This occurs most commonly with data sets where the majority of values are censored and "tied" at the lower detection limit, but occasional higher values are also

[6] Darken P., C. Zipper, G. Holtzman and E. Smith. 2002. Serial correlation in water quality variables: Estimation and implications for trend analysis. Water Res. Research 38:22 1-5.

observed. If there is a significant change in the frequency of uncensored values during the period of interest then a trend can be detected but, since the majority of the values are tied, the estimated (median) slope would still be zero (0.000). Of the 277 significant 20-year trends detected, 7 of 14 (50.0%) for bacteria, 9 of 39 (23.1%) for phosphorus, 9 of 42 (21.4%) for TKN, 3 of 27 (11.1%) for TSS had slope values equal to zero, and no predictions of future values were possible.

Long-Term (20-Year) versus Shorter-Term (10-Year) Trends

Because Seasonal Kendall Tau trend analysis measures the significance of 'monotonic' or unidirectional changes in water quality during a specified time interval, a change in the direction of a trend during the interval of interest may limit the procedure's ability to detect significant water-quality changes during that period. This is especially true if the change in direction occurred near the mid-point of the time interval, and the duration and uniformity of the opposing trends are similar. In such cases the effects of opposing trends may completely cancel one another and neither one would be detected. In addition, while water quality trends are often evaluated over long-term time series, the most recent changes in water quality are generally considered to be more important. Numerous restoration projects have been implemented within the last ten years, and water resource managers recognize that trend detection during this period is an important tool in judging the effectiveness of those efforts. Consequently, trends were evaluated for both long-term (20-year) and shorter term (10-year) periods during this study.

The visual evaluation of possible changes or even reversals in trends may be accomplished with the use of simple graphical presentations of measured water quality values as a function of time. Such graphical summaries of water quality data are another output feature of the WQ3 software. The plots of total nitrogen (TN or NITROGEN) concentrations vs. time, as illustrated in Figures 2.4-1, 2.4-2 and 2.4-3 on the following pages, demonstrate the dangers in interpreting long-term trend data without a critical examination of the underlying data structure. Visual perceptions of the patterns are often very sensitive to changes in the direction of trends and may provide relatively precise estimates of when they occurred, but they are unable to quantify or determine the statistical significance of such changes. Additional trend analyses, carried out on separate time blocks, are the most reliable method for quantifying these shorter-term trends, even though the reduced number of observations generally lowers the significance level of the results.

In Figure 2.4-1, for example, Kendall Tau trend analysis at a site on the Chickahominy River identified a significant increasing trend in TN for the thirty-five-year period 1970 – 2005 (significance probability - dependent P-value = 0.014), during which time the total nitrogen concentrations increased an average of 0.03 mg/L per year (slope of the trend line). The straight broken (blue) line in the figure represents the median linear trend for the entire period. The curved continuous (green) line in the figure is the result of a type of moving average calculation for the nitrogen values. The specific method for calculating this moving average is called "locally-weighted scatter plot smoothing", commonly referred to with the acronym "LOWESS" (Cleveland, 1979[7]). In the smoothing process, values near the center of the local time interval used to calculate the moving average are given more weight than more distant values, and nitrogen values near the average for the interval are given more weight than values which deviate greatly from it. Visual examination of the LOWESS line reveals that, in spite of some local variation, the moving average tends to increase from 1970 through 1995, but tends to decrease thereafter (1995-2005). The tendency during the first 25 years of the 35-year dataset predominates and masks the opposing tendency observed in the final ten years. When analyzing the effectiveness of management practices, recent water quality trends are of more interest to environmental managers than those from 35 years ago, and more recent changes in the direction of trends are important in interpreting the results of newly applied management practices. For this reason, the time period to be included in trend analyses must be carefully considered so that historic water quality conditions do not overly influence the interpretation of more recent data.

When the data set summarized in Figure 2.4-1 was trimmed to include only the last twenty years, as illustrated in Figure 2.4-2, no significant trend was detected (dependent P-value = 0.882, slope = 0.006 mg/L per year). Unfortunately, reducing the time period also reduces the number of data points included in the analysis, which makes it more difficult to detect significant trends. In this case, the duration and strength of the opposing ten-year trends (1985-1995 vs.1995-2005) were also approximately equal and cancelled one another almost perfectly. What is important in this case is not the strength of the overall trend but the fact that the trend appears to change during the period of interest. Three important questions arise from this observation. 1) How much do trends from the two shorter periods differ?, 2) Are the differences significant?, 3) Are the changes in desirable or not.

[7] Cleveland, W. S. 1979. Robust locally weighted regression and smoothing scatterplots. Journal of the American Statistical Association 73:829-836.

When the two ten-year intervals (1985-1995 vs. 1995-2005) of Figure 2.4-2 were evaluated separately, trend analyses revealed the following results:

Period	Significance Probability	Slope
1985-1995	**Dependent p = 0.1032, not significant**	**+0.088 mg/L per year**
1995-2005	**Dependent p = 0.0131, significant**	**-0.419 mg/L per year**

The results from the most recent ten-year interval (1995-2005) were highly significant, in spite of the reduced number of observations included, and are illustrated in Figure 2.4-3. On the average, total nitrogen values declined by 0.42 mg/L per year during this ten-year period. Although this rate of reduction in total nitrogen concentrations may not be sustainable on a permanent basis, such a reduction does represent a desirable trend. Just as important, and perhaps even more informative, is the fact that the initial (undesirable) long-term trend observed from 1970 through 1995 was reversed in a desirable direction.

In the example above, the patterns of water quality change over time were fairly clear and easy to interpret. When such patterns are examined at numerous water quality monitoring stations within the same drainage basin, or across the Commonwealth as a whole, the results may vary considerably among sites and are often not so easy to interpret, individually or as a group. Changes in trend at some individual sites may be subtle and appear insignificant, or may even occur in an opposing, undesirable direction. Localized trends, examined on a site-by-site basis, are often difficult to define and their interpretations may even contradict one another from one site to the next.

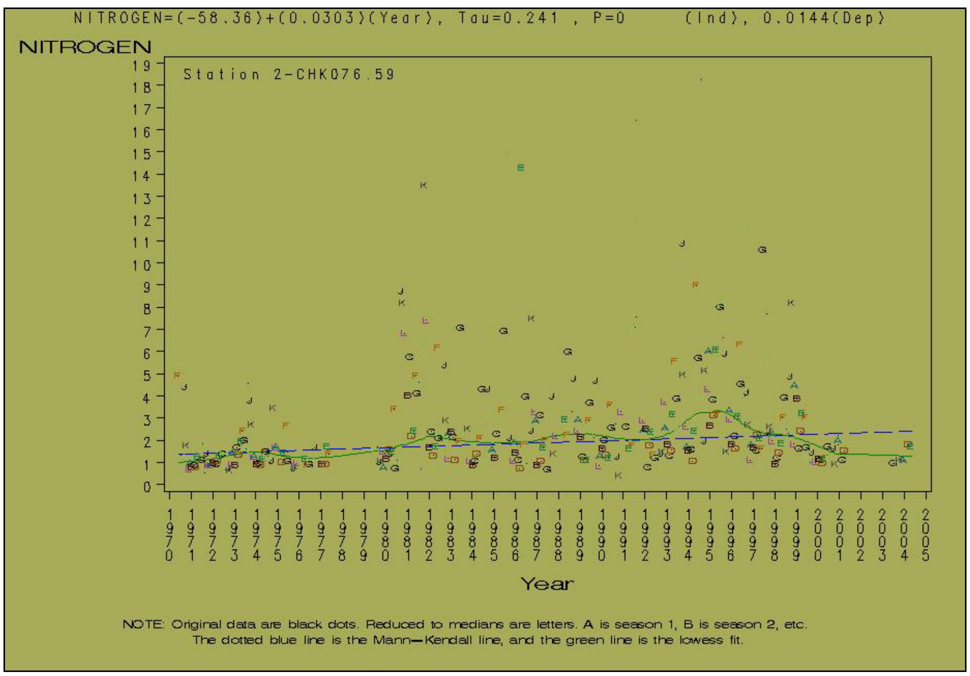

Figure 2.4-1. Total Nitrogen Trend at Station 2-CHK076.59 on the Chickahominy River, 1970-2005. Thirty-five years of monitoring reveal a significant increasing trend in total nitrogen (Dependent P-value = 0.0144). An increasing trend (0.03 mg/L yr^{--1}) during the twenty-five year period from 1970 through 1995 dominates the overall trend analysis results.

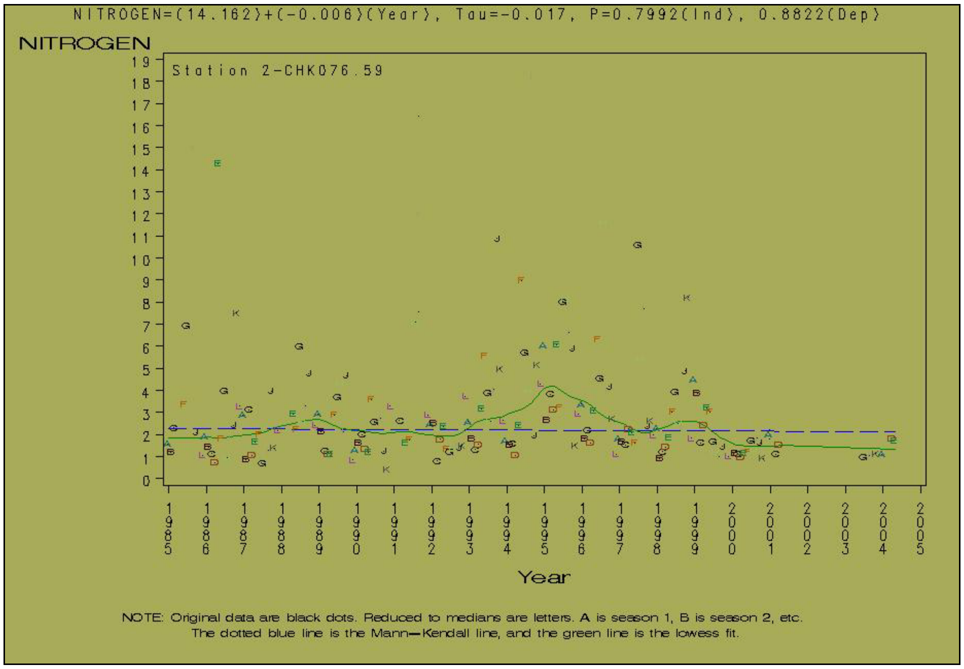

Figure 2.4-2. Total Nitrogen Trend at Station 2-CHKO76.59 on the Chickahominy River, 1985-2005. Twenty years of more recent monitoring reveal no significant trend in total nitrogen (Dependent P-value = 0.8822). Opposing trends from 1985 through 1995 and from 1995 through 2004 cancel one another and result in no significant trend for the total period.

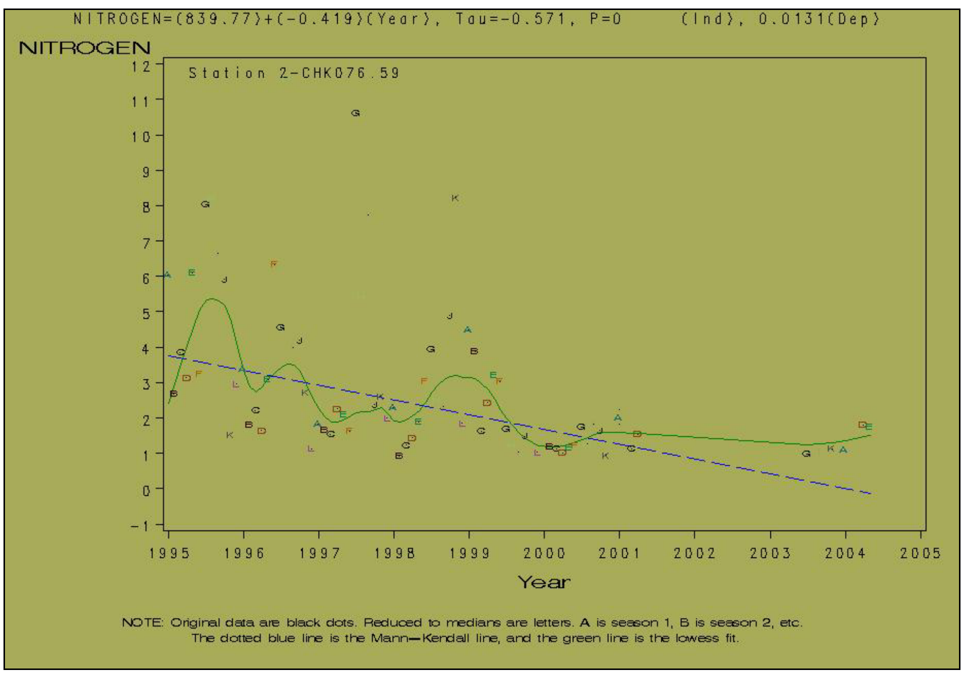

Figure 2.4-3. Total Nitrogen Trend at Station 2-CHK076.59 on the Chickahominy River 1995-2005. Ten years of the most recent monitoring data reveal a highly significant downward trend in total nitrogen. (Dependent P-value = 0.0131, rate of change = -0.42 mg/L yr^{-1}).

In later sections of this chapter (Summarizing and Evaluating Site-Specific and Regional Trends), analyses of both the 20-year (1985 to 2004) and 10-year (1995 to 2004) periods are discussed and compared. The 10-year block has only half as many observations as the 20-year period and consequently would demonstrate fewer statistically significant trends at the 95% confidence level, even if the water quality change were to remain constant. Because of the reduced number of observations in the most recent ten-year period, the confidence level interpreted as being significant was relaxed from 95% to 90%. This facilitates the identification of more numerous apparent trends, but our confidence in a specific trend's being truly significant is slightly reduced (by 5%).

Comparison of Flow-Adjusted and Non-Flow-Adjusted Results

The effect of stream flow or discharge volume on concentrations is often considered an important factor in water quality trend analyses. Stream flow may vary considerably from season to season or from year to year, and may demonstrate a significant trend of its own over the period of interest. The values of some water quality parameters, such as total suspended solids (TSS), may increase elevated flow conditions as a direct consequence of the precipitation that caused the elevated flow. The concentrations of other parameters, such as dissolved nutrients and bacteria, may be reduced by dilution under the same conditions, although such relationships can vary in a complex manner during the early *versus* later stages of a precipitation/high-discharge event! In either case, the value of the water quality variable is considered to be 'flow dependent'. Therefore the effects of discharge on measured values of the variable must be considered conducting and interpreting trend analyses.

Concurrent discharge measurements are often not available with water quality monitoring data. Statewide, the number of flow gauging stations with continuous 20-year records (69) was far less than the number of trend monitoring stations in free-flowing waters. Another contributing factor restricting the application of flow adjustments is the fact that many trend stations are located in reservoirs or in tidal waters, where flow measurement is not relevant. In the present study, separate analyses were performed for trend in flow at all available gauging stations in the state for which median daily discharge measurements were continuous during the period of record (1985 to 2004) in order to determine whether statistically significant trends in flow existed. No significant trends in flows were detected, either for 20-year long-term ($p \leq 0.05$) or for 10-year shorter-term ($p \leq 0.10$) records[8]. Consequently, it was concluded that neither long-term nor shorter-term trends in flow should have any significant influence on water quality trends at monitoring sites where flow correction was not available. Discharge volume did, however, vary considerably among seasons. The seasonally-blocked characteristic of the Kendall procedure automatically compensates for the majority of this seasonal variation.

When daily flow data were available at a specific trend monitoring site, preliminary trend analyses were performed both with and without, flow adjustment. The results of these comparisons were interpreted to test the conclusion reached above relative to sites without flow data. Pair-wise comparisons of flow-adjusted and non-flow-adjusted trend analysis results were carried out at 37 sites for 20-year trends (1985-2004) and at 44 sites for 10-year trends (1995-2004). More trend stations were collocated with continuous gauging sites during the most recent 10-year period. This resulted in 332 parameter-site pairs for 20-year and 366 parameter-site pairs for 10-year comparisons. In comparing flow-adjusted and non-flow-adjusted trend analysis results, three outputs from the Kendall procedure are of primary interest: (1) changes in the absolute value of *Tau*, which is a measure of the <u>uniformity</u> (monotonicity) of the trend, (2) changes in the Thiel-Sen slope, which is a measure of the <u>direction</u> and <u>strength</u> of the trend, and (3) changes in the dependent p-value (pvalcovs), which is a measure of the <u>statistical significance</u> of the trend. The results of comparing these three outputs across all pair-wise comparisons are summarized in Table 2.4-2, below.

As a rule, the addition of flow-adjustment only slightly changed the value of the output parameters and the variations observed among differences were relatively symmetrical around a median difference of 0.000, signifying no change (see Table 2.4-2). In most cases, this pattern of no systematic directional change was characteristic of each individual water quality parameter (e.g., DO, TN, TP, pH, TEMP and TSS), as well as for the total parameter suite as summarized in Table 2.4-2. Two exceptions to this pattern were observed. Slight increases occurred in the average absolute value of *tau*, indicating a small improvement in trend uniformity as a result of flow adjustment. This difference was statistically significant ($p \leq 0.05$) for the 20-year trends, but not for the 10-year trends. Even the significant difference observed (median difference = + 0.006) represented a relatively trivial change in trend interpretation. Comparatively large unsymmetrical changes, primarily in a negative direction, were noted in the values of the Thiel-Sen slope for bacterial trends following flow adjustment. The differences related to changes in bacterial trends are evident in the more extreme values of 'Average Difference', Maximum Difference' and 'Minimum Difference' in columns (2) and (6) of the table. Following the removal of the bacterial results from the global summaries in columns (3) and (7) of the table, the differences in the Thiel-Sen slope for the remaining parameters were relatively symmetrical about a near-zero median change.

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[8] A notable three-year drought (and consequent reduced discharge rates) during calendar years 2000 – 2002 was evident in graphic outputs of the ten-year flow trend analyses. Subsequent years returned to above average rainfall and discharge and no significant 10-year trends in flow net were observed.

	20-Year Long-term Trends				10-Year Short-term Trends			
	(1) Changes in Absolute Tau Value	(2) Changes in Slope (w BACT)	(3) Changes in Slope (w/o BACT)	(4) Changes in PCov Value	(5) Changes in Absolute Tau Value	(6) Changes in Slope (w BACT)	(7) Changes in Slope (w/o BACT)	(8) Changes in PCov Value
Negative Changes	133	169	146	162	161	168	145	179
Positive Changes	188	145	133	165	190	182	166	184
No Change	11	18	16	5	15	16	14	3
Total count	332	332	295	332	366	366	325	366
Average Difference	0.012	-2.106	0.000	0.005	0.004	-0.888	-0.002	-0.002
Maximum Difference	0.223	4.437	0.170	0.822	0.405	17.711	1.066	0.880
90th Pecentile	0.073	0.030	0.024	0.248	0.112	0.216	0.119	0.354
75th Pecentile	0.038	0.004	0.003	0.104	0.048	0.017	0.014	0.150
Median Difference	0.006	0.000	0.000	0.000	0.004	0.000	0.000	0.000
25th Pecentile	-0.016	-0.004	-0.002	-0.062	-0.038	-0.019	-0.008	-0.134
10th Pecentile	-0.043	-0.056	-0.022	-0.241	-0.108	-0.267	-0.132	-0.387
Minimum Difference	-0.230	-685.511	-0.126	-0.956	-0.373	-283.709	-2.125	-0.949

Table 2.4-2. Summary of Pair-wise Comparisons of Non-Flow-Adjusted and Flow-Adjusted Seasonal Kendall *Tau* Trend Analysis Output Parameters. Differences were calculated as the flow-adjusted value minus the non-flow-adjusted value. The parenthetic observations "w BACT" and "w/o BACT" refer to the inclusion (w - with) and exclusion (w/o - without), respectively, of bacterial measurements in the corresponding columns of the summary table.

The pair wise comparisons of flow-adjusted *versus* non-flow-adjusted trend pairs revealed few major differences (Table 2.4-3). Of 332 paired 20-year trends, 35 pairs were found to be statistically significant ($p \leq 0.05$) using both measures and 280 pairs were not significant using both measures. Only 17 (5.1%) of the 332 20-year trend pairs yielded results that differed in statistical significance. The confidence level required for significance was relaxed from 95% to 90% for 10-year trend analyses, because of the reduced numbers of observations. Among 366 paired 10-year trends, 15 pairs were in agreement and significant ($p \leq 0.10$) and 308 pairs were in agreement and non-significant. Forty-three (11.7%) of the 366 10-year pairs yielded results that differed in statistical significance. In those cases where the interpretation of significance differed between flow-adjusted and non-flow-adjusted results, the significance probabilities (p-values) were always near the critical values for rejection of the Null Hypothesis (respective confidence levels of 95% and 90%). In each case, the percentage of reversals closely approximated the expected Type I (false positive) error rates of 5% and 10%, respectively.

	Significant Trends with and without Flow Adjustment					
	20-Year Long-term Trends			10-Year Short-term Trends		
	Pairs in Agreement ($p \leq 0.05$)	Flow Adjusted Only ($p \leq 0.05$)	Flow Unadjusted Only ($p \leq 0.05$)	Pairs in Agreement ($p \leq 0.10$)	Flow Adjusted Only ($p \leq 0.10$)	Flow Unadjusted only ($p \leq 0.10$)
Bacteria (BACT)	0	1	1	4	0	1
Dissolved Oxygen (DO)	6	2	1	1	3	0
Total Nitrogen (TN)	9	2	0	2	3	5
Oxidixed Nitrogen (NOX)	10	2	0	2	6	4
Total Kjeldahl Nitrogen (TKN)	4	1	1	1	1	2
Total Phosphorus (TP)	3	0	1	0	1	2
Acidity (pH)	3	1	1	3	0	2
Water Temperature (TEMP)	0	1	0	1	5	1
Total Suspended Solids (TSS)	0	0	2	1	1	6
Total Significant Trends	35	10	7	15	20	23

Table 2.4-3. Summary of Comparisons in Interpretations among Matched Pairs of Flow-adjusted and Non-Flow-Adjusted Trend Analyses. Note that the confidence level required for significance was relaxed from 95% to 90% for 10-year trend analyses, where reduced numbers of observations increased the difficulty of trend detection.

These results support the assumption that flow-adjustment would not induce significant differences in trend interpretation once it was confirmed than no long-term trend existed in flow itself. Because the majority of trend stations included in this study did not have simultaneous stream discharge measurements, only results from non-flow-adjusted trend analyses are included in the following discussions of statewide 20-year and 10-year trends. It should be emphasized, however, that when significant trends in stream flow are confirmed, the inclusion of flow adjustment may be extremely important.

Summarizing and Evaluating Site Specific and Regional Trends

Significant trends identified in the long-term (20-year) and more recent mid-term (10-year) trend analyses are enumerated and characterized in Tables 2.4-4, 2.4-5, 2.4-6 and 2.4-7 below. Tables 2.4-4 (key parameters) and 2.4-5 (supplemental parameters) identify those 20-year trends that were determined to be significant at the 95% confidence level (dependent p-value ≤ 0.05), by major drainage basin and parameter. Positive columns (+) list the percentages of those with increasing values or concentrations and negative columns (-) list the percentages of those with decreasing values or concentrations. Tables 2.4-6 and 2.4-7 are equivalent to Tables 2.4-4 and 2.4-5, respectively, except they include the significant trends (dependent p-value ≤ 0.10) identified during the most recent ten year time period, beginning in 1995. A map illustrating the statewide distribution of the stations included in these analyses is presented in Figure 2.4-4. The same stations, and additional information about their respective locations, are listed in Appendix F.

Of 2279 site-parameter pairs evaluated for 10-year trends, 433 (19.0%) had insufficient data (too few data points) to calculate short-term trend analyses. As mentioned above, in the discussion of long-term vs. shorter-term trends, because of the reduced number of observations in the most recent ten-year period, the confidence level interpreted as being significant for ten-year trends was relaxed from 95% to 90%. This facilitated the identification of more numerous apparent trends at the expense of a slightly lower confidence in a specific trend's being truly significant. Tables 2.4-6 and 2.4-7 identify those shorter-term trends that were determined to be significant at the 90% confidence level (p-value ≤ 0.10). As in the previous tables, positive columns (+) are those with increasing values or concentrations and negative columns (-) are those with decreasing values or concentrations.

Although the tables above summarize the percentages of significant trends, it should be pointed out that most sites did not demonstrate significant trends for the majority of the parameters evaluated. Several factors may be responsible for the failure to detect significant trends in so many cases. First, long-term changes in some water quality variables may not be occurring at those sites. If water quality is stable, in spite of increasing environmental pressures due to population growth and land development, this may be considered a good sign. Secondly, the development and subsequent implementation of TMDLs is a relatively recent innovation. Significant changes in water quality induced within the last five to ten years may be reversing previous trends, but have not yet had sufficient time to become statistically significant themselves. The difficulty in identifying non-linear or reversing trends was discussed above.

BACTERIA (FC or BACT)

Various groups of bacteria have been utilized as indicators of contamination of ambient waters by fecal material, which may also contain other pathogenic organisms. Human health-related bacterial water quality standards are currently in a period of transition from fecal coliform-based bacterial criteria to *Escherichia coli*-based (freshwater) and *Enterococci*-based (saltwater) criteria. Prior to the summer of 2003, bacterial monitoring was carried out predominantly with fecal coliform bacteria, and they are the only group of bacteria considered in the present trend analyses. Future trend analyses will consider *E. coli* and *Enterococci* concentrations, once sufficient data records for trend analysis of these bacterial groups have been accumulated. Historically, two equivalent test methods have been used to enumerate fecal coliform bacteria colonies. For the trend analyses performed here, the fecal coliform concentrations were derived from the combination of STORET parameter codes 31615 (MPN = Most Probable Number) and 31616 (MF = Membrane Filtration). In the very rare circumstances where numeric values for both methods exist for the same sampling event, the 31615 value was used because the quantitation range is greater for the MPN method.

Bacterial results are presented as fecal coliform (FC or BACT) concentrations expressed as the number of colony-forming units (cfu) per 100 mL of ambient water sample. Humans and other warm blooded animals harbor large numbers of FC in their intestinal tracts. The presence of FC is an indication that the water is contaminated with untreated human sewage or animal feces. Some major sources of FC are direct discharge of untreated human sewage, leaking sewer lines, concentrated animal feeding operations (CAFO), farm and urban stormwater runoff, and fecal wastes from domestic pets and wildlife.

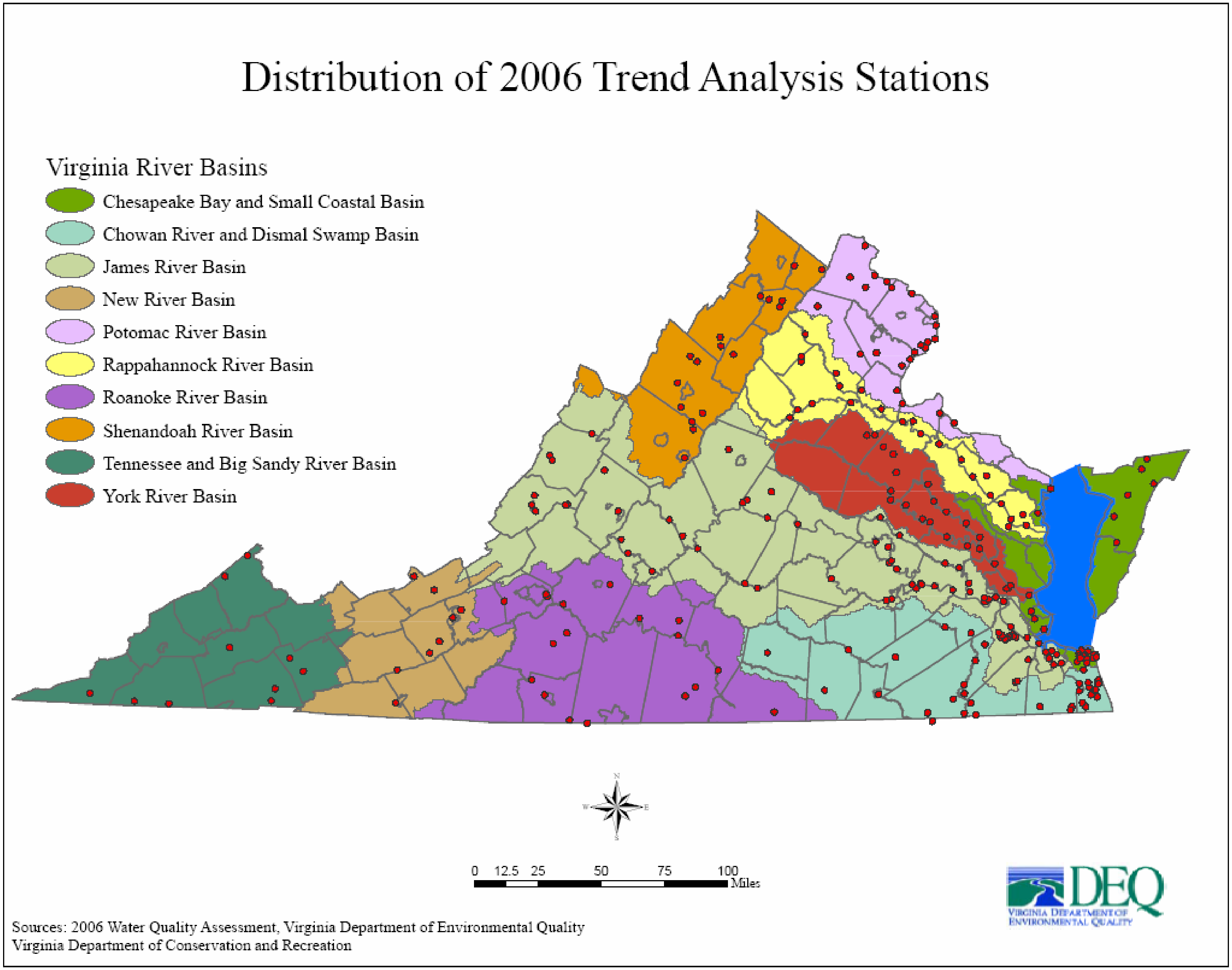
Distribution of 2006 Trend Analysis Stations
Virginia River Basins
Chesapeake Bay and Small Coastal Basin
Chowan River and Dismal Swamp Basin
James River Basin
New River Basin
Potomac River Basin
Rappahannock River Basin
Roanoke River Basin
Shenandoah River Basin
Tennessee and Big Sandy River Basin
York River Basin
0 12.5 25 50 75 100
Miles
DEQ
Virginia Department of Environmental Quality
Sources: 2006 Water Quality Assessment, Virginia Department of Environmental Quality
Virginia Department of Conservation and Recreation

Figure 2.4-4. The Statewide Distribution of Trend Analysis Stations for the 2006 Report.

	BACTERIA				NITROGEN				PHOSPHORUS				TOTAL SUSPENDED SOLIDS			
BASIN	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT
POTOMAC SHENANDOAH	0.0%	0.0%	100.0%	34	2.8%	25.0%	72.2%	36	5.7%	8.6%	85.7%	35	2.8%	8.3%	88.9%	36
JAMES	0.0%	17.5%	82.5%	57	6.5%	21.7%	71.7%	46	0.0%	37.3%	62.7%	59	1.6%	8.2%	90.2%	61
RAPPAHANNOCK	0.0%	0.0%	100.0%	18	0.0%	0.0%	100.0%	11	0.0%	0.0%	100.0%	19	5.0%	10.0%	85.0%	20
ROANOKE	0.0%	6.3%	93.8%	16	6.3%	12.5%	81.3%	16	0.0%	20.0%	80.0%	15	0.0%	6.3%	93.8%	16
CHOWAN	7.1%	0.0%	92.9%	14	0.0%	25.0%	75.0%	20	0.0%	20.0%	80.0%	20	0.0%	35.0%	65.0%	20
TENNESSEE BIG SANDY	0.0%	33.3%	66.7%	3	0.0%	0.0%	100.0%	3	0.0%	0.0%	100.0%	2	0.0%	0.0%	100.0%	3
CHESAPEAKE BAY, OCEAN, SMALL COASTAL	4.8%	0.0%	95.2%	21	5.3%	5.3%	89.5%	19	5.3%	21.1%	73.7%	19	0.0%	15.8%	84.2%	19
YORK	0.0%	0.0%	100.0%	14	57.1%	0.0%	42.9%	7	0.0%	0.0%	100.0%	15	12.5%	6.3%	81.3%	16
NEW	0.0%	0.0%	100.0%	6	0.0%	0.0%	100.0%	5	0.0%	0.0%	100.0%	5	0.0%	0.0%	100.0%	5
TOTALS	1.1%	6.6%	92.3%	183	6.1%	16.6%	77.3%	163	1.6%	19.0%	79.4%	189	2.6%	11.2%	86.2%	196

Table 2.4-4. A Summary of Virginia's Significant Long-Term (20-year) Trend Analysis Results for the Period 1985–2004, by Key Parameter and Basin. Tabled values are percentages of total trend analyses calculated. Trends significant at the 95% confidence level (p-value ≤ 0.05) are identified in the table. ('+' indicates an increasing trend, '-' indicates a decreasing trend, and 'NO CHANGE' indicates the percent of samples/observations showing no significant trend).

	DISSOLVED OXYGEN				NITROGEN OXIDIZED				PH				TEMPERATURE				TOTAL KJELDAHL NITROGEN			
BASIN	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT
POTOMAC SHENANDOAH	5.6%	13.9%	80.6%	36	5.7%	25.7%	68.6%	35	5.7%	5.7%	88.6%	35	2.8%	0.0%	97.2%	36	8.6%	17.1%	74.3%	35
JAMES	9.7%	17.7%	72.6%	62	4.7%	34.9%	60.5%	43	3.2%	12.9%	83.9%	62	1.6%	1.6%	96.8%	62	13.6%	15.3%	71.2%	59
RAPPAHANNOCK	10.0%	0.0%	90.0%	20	0.0%	11.1%	88.9%	9	0.0%	10.0%	90.0%	20	0.0%	0.0%	100.0%	20	15.8%	0.0%	84.2%	19
ROANOKE	5.9%	11.8%	82.4%	17	6.3%	12.5%	81.3%	16	11.8%	5.9%	82.4%	17	0.0%	0.0%	100.0%	17	6.3%	0.0%	93.8%	16
CHOWAN	0.0%	35.7%	64.3%	14	0.0%	5.0%	95.0%	20	0.0%	33.3%	66.7%	15	0.0%	15.0%	85.0%	20	5.0%	15.0%	80.0%	20
TENNESSEE BIG SANDY	0.0%	0.0%	100.0%	3	33.3%	0.0%	66.7%	3	0.0%	0.0%	100.0%	3	0.0%	0.0%	100.0%	3	0.0%	0.0%	100.0%	3
CHESAPEAKE BAY, OCEAN, SMALL COASTAL	12.5%	25.0%	62.5%	16	5.3%	0.0%	94.7%	19	0.0%	21.1%	78.9%	19	5.3%	10.5%	84.2%	19	0.0%	0.0%	100.0%	19
YORK	6.3%	6.3%	87.5%	16	28.6%	0.0%	71.4%	7	0.0%	6.3%	93.8%	16	6.3%	0.0%	93.8%	16	46.7%	0.0%	53.3%	15
NEW	0.0%	20.0%	80.0%	5	0.0%	0.0%	100.0%	5	0.0%	0.0%	100.0%	5	0.0%	0.0%	100.0%	5	0.0%	0.0%	100.0%	5
TOTALS	7.4%	15.3%	77.2%	189	5.7%	17.8%	76.4%	157	3.1%	12.0%	84.9%	192	2.0%	3.0%	94.9%	198	12.0%	9.4%	78.5%	191

Table 2.4-5. A Summary of Virginia's Significant Long-Term (20-year) Trend Analysis Results for the Period 1985–2004, by Supplemental Parameter and Basin. Tabled values are percentages of total trend analyses calculated. Trends significant at the 95% confidence level (p-value ≤ 0.05) are identified in the table. ('+' indicates an increasing trend, '-' indicates a decreasing trend, and 'NO CHANGE' indicates the percent of samples/observations showing no significant trend).

	BACTERIA				NITROGEN				PHOSPHORUS				TOTAL SUSPENDED SOLIDS			
BASIN	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT
POTOMAC SHENANDOAH	0.0%	13.5%	86.5%	37	0.0%	2.8%	97.2%	36	5.9%	2.9%	91.2%	34	0.0%	8.3%	91.7%	36
JAMES	1.7%	27.6%	70.7%	58	2.0%	5.9%	92.2%	51	0.0%	6.8%	93.2%	44	0.0%	5.6%	94.4%	72
RAPPAHANNOCK	0.0%	7.7%	92.3%	13	0.0%	14.3%	85.7%	7	0.0%	14.3%	85.7%	7	0.0%	0.0%	100.0%	20
ROANOKE	0.0%	25.0%	75.0%	16	17.6%	17.6%	64.7%	17	0.0%	5.9%	94.1%	17	0.0%	52.9%	47.1%	17
CHOWAN	0.0%	27.3%	72.7%	33	0.0%	12.1%	87.9%	33	0.0%	7.1%	92.9%	28	0.0%	24.2%	75.8%	33
TENNESSEE BIG SANDY	0.0%	11.1%	88.9%	9	11.1%	0.0%	88.9%	9	0.0%	0.0%	100.0%	4	0.0%	30.0%	70.0%	10
CHESAPEAKE BAY, OCEAN, SMALL COASTAL	0.0%	8.3%	91.7%	12	0.0%	0.0%	100.0%	13	0.0%	7.7%	92.3%	13	23.1%	7.7%	69.2%	13
YORK	5.9%	11.8%	82.4%	17	15.4%	0.0%	84.6%	13	7.7%	0.0%	92.3%	13	13.0%	4.3%	82.6%	23
NEW	0.0%	0.0%	100.0%	8	12.5%	0.0%	87.5%	8	0.0%	0.0%	100.0%	7	0.0%	0.0%	100.0%	8
TOTALS	1.0%	19.2%	79.8%	203	4.3%	6.4%	89.3%	187	1.8%	5.4%	92.8%	167	2.6%	12.5%	84.9%	232

Table 2.4-6. A Summary of Virginia's Significant Mid-Term (most recent 10 years) Trend Analysis Results for the Period 1995–2004, by Key Parameter and Basin. Tabled values are percentages of total trend analyses calculated. Trends significant at the 90% confidence level (p-value ≤ 0.10) are identified in the table. ('+' indicates an increasing trend, '-' indicates a decreasing trend, and 'NO CHANGE' indicates the percent of samples/observations showing no significant trend).

	DISSOLVED OXYGEN				NITROGEN OXIDIZED				PH				TEMPERATURE				TOTAL KJELDAHL NITROGEN			
BASIN	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT	+	-	NO CHANGE	COUNT
POTOMAC SHENANDOAH	2.8%	2.8%	94.4%	36	0.0%	17.1%	82.9%	35	0.0%	8.6%	91.4%	35	11.4%	5.7%	82.9%	35	8.6%	0.0%	91.4%	35
JAMES	2.8%	4.2%	93.0%	71	2.0%	6.0%	92.0%	50	6.9%	8.3%	84.7%	72	4.2%	0.0%	95.8%	72	8.2%	2.0%	89.8%	49
RAPPAHANNOCK	0.0%	0.0%	100.0%	20	0.0%	14.3%	85.7%	7	0.0%	0.0%	100.0%	20	5.0%	5.0%	90.0%	20	14.3%	0.0%	85.7%	7
ROANOKE	5.9%	5.9%	88.2%	17	17.6%	29.4%	52.9%	17	35.3%	17.6%	47.1%	17	0.0%	0.0%	100.0%	17	17.6%	11.8%	70.6%	17
CHOWAN	0.0%	6.1%	93.9%	33	0.0%	0.0%	100.0%	33	3.0%	24.2%	72.7%	33	27.3%	0.0%	72.7%	33	0.0%	12.5%	87.5%	32
TENNESSEE BIG SANDY	11.1%	0.0%	88.9%	9	22.2%	0.0%	77.8%	9	44.4%	0.0%	55.6%	9	0.0%	22.2%	77.8%	9	0.0%	0.0%	100.0%	9
CHESAPEAKE BAY, OCEAN, SMALL COASTAL	7.7%	0.0%	92.3%	13	0.0%	7.7%	92.3%	13	0.0%	30.8%	69.2%	13	7.7%	0.0%	92.3%	13	0.0%	0.0%	100.0%	13
YORK	4.3%	0.0%	95.7%	23	7.7%	7.7%	84.6%	13	8.7%	4.3%	87.0%	23	8.7%	0.0%	91.3%	23	14.3%	0.0%	85.7%	14
NEW	0.0%	12.5%	87.5%	8	12.5%	0.0%	87.5%	8	25.0%	12.5%	62.5%	8	0.0%	0.0%	100.0%	8	0.0%	12.5%	87.5%	8
TOTALS	3.0%	3.5%	93.5%	230	4.3%	9.2%	86.5%	185	8.7%	11.3%	80.0%	230	8.7%	2.2%	89.1%	230	7.1%	4.3%	88.6%	184

Table 2.4-7. A Summary of Virginia's Significant Mid-Term (most recent 10 years) Trend Analysis Results for the Period 1995–2004, by Supplemental Parameter and Basin. **Tabled values are percentages of total trend analyses calculated. Trends significant at the 90% confidence level (p-value ≤ 0.10) are identified in the table. ('+' indicates an increasing trend, '-' indicates a decreasing trend, and 'NO CHANGE' indicates the percent of samples/observations showing no significant trend).**

Of the 183 monitoring stations analyzed for 20-year trends in bacterial concentrations, only two (1.1%) had significant increasing trends, while 12 (6.6%) exhibited significant decreasing trends. A decreasing trend in bacterial concentration indicates improving water quality and is considered to be desirable. The most notable improvement in bacterial concentrations has occurred in the James basin, which had 10 of the 12 significant decreasing trends. However, 92.3% of those stations monitored statewide showed no significant trend in fecal coliform bacterial counts.

The slope estimators at stations with significant trends were used to calculate estimates of the expected bacterial concentrations at those sites in 2008. These results predict bacteria concentrations to exceed the water quality standard for fecal coliform bacteria at three sites within the next assessment cycle. One station of concern is on Thalia Creek (7-THA000.76) in the urban Lynnhaven River drainage of Virginia Beach. The other two stations of concern are on Shingle Creek (2-SGL001.00) and on the Nansemond River (2-NAN019.14), both in the James River drainage. It should be noted that the bacteria trend for both stations is decreasing in concentration but will still remain high enough to exceed the instantaneous water quality standard in 2008. Both of these stations were already listed for bacterial impairment in the 2004 Integrated 305(b)/303(d) Report.

Of the 203 sites evaluated for the most recent 10-years period, 58 (22.3%) had insufficient data (too few data points) to calculate short-term trend analyses. Among the stations with apparent 10-year trends in bacterial concentrations, the pattern indicates greater decreases in bacteria than the 20-year results. The number identified as increasing remained at two, although they were in different basins and at different sites from the significantly increasing 20-year trends. There was, however, an increase in the number of decreasing (desirable) trends identified; 39 (19.2%) of 203 sites, distributed primarily among the James, Chowan, Potomac/Shenandoah and Roanoke basins. This increase in the number of apparent decreasing trends is evidently not a direct result of the relaxed confidence requirement, because a similar increase in the numbers of detected 10-year trends was not observed in most other parameters analyzed. A portion of the recent decrease in bacterial counts may have resulted from the sustained efforts in recent years to control non-point sources of contamination by the implementation of Best Management Practices (BMPs) to increase riparian buffers, control access to streams by livestock, to control stormwater runoff, etc., even prior to the recent emphasis on the TMDL Program.

DISSOLVED OXYGEN (DO)

Dissolved oxygen (DO) is a measure of the concentration of free dissolved O_2 gas in the ambient water column. Much of the oxygen dissolved in ambient waters comes directly from the atmosphere, but its concentration (mg/L) depends upon water temperature, the degree of mixing taking place at the surface and within the water column, and the rate of oxygen depletion caused by chemical and biological oxygen demands. Water's theoretical maximum capacity to hold dissolved oxygen is determined by its temperature and salinity, as well as by atmospheric pressure. Because of the dependence of DO concentration on the physical properties of atmospheric pressure and water temperature and the chemical property of chlorinity as measured by either salinity or specific conductance, DO must be converted to a standard unit of measurement to be useful in trend analysis[9].

All dissolved oxygen concentrations were converted to % Saturation of dissolved oxygen prior to calculating the DO trends as reported.

DO is essential to the survival of desirable animal and plant life in aquatic environments. Aquatic animals are completely dependent upon dissolved oxygen for their metabolism. During the daylight hours green plants can produce their own oxygen from carbon dioxide via photosynthesis, but they also must depend upon dissolved oxygen to support their metabolism during the night.

Observed DO concentrations can also be influenced by water turbulence, sunlight, nutrient concentrations, organic pollution and algae, among other things. While temperature and the degree of mixing within the water column vary naturally, oxygen concentrations can also be directly affected by human-induced

[9] For example, given two identical values for dissolved oxygen of 7.00 mg/L and two identical salinity values of 15 ppt but with temperature measurements of 25 C and 20 C, the DO percent saturations would be calculated to be 92.3 %sat and 84.1 %sat, respectively. DO %sat is therefore a better measure of the actual quantity of DO, relative to the potential carrying capacity of dissolved oxygen in water. Obviously, if DO concentrations (mg/L) were to be used the two values of 7.00 mg/L would be considered tied.

changes in riparian vegetation, the lack of which may cause warming of small streams, by pollution with biodegradable organic substances, and by nutrient enrichment. Nutrient enrichment may stimulate excessive growth and reproduction among aquatic plants, both macrophytes and algae. While the resultant increase in photosynthesis may elevate oxygen levels during the day, those plants will also respire during the night to support their metabolism. When plants (including algae) are abundant, nighttime respiration can deplete dissolved oxygen. In addition, the decomposition of dying plants and other organic materials often produces a biological oxygen demand that depresses dissolved oxygen levels even further. This process, called eutrophication, results in unfavorable conditions for fish and other aquatic organisms.

Paradoxically, over a long period of time, a decreasing DO trend at locations where the median DO is relatively high may be an indication of improving water quality. This condition is possible because DEQ water monitoring data is acquired primarily from measurements taken during the daylight hours, when aquatic plants (including algae) tend to be photosynthetically active and producing oxygen. For example, if the concentration of nutrients were to decrease over the analysis period (normally considered to be a favorable trend), then daytime concentrations of DO might also decrease because algal photosynthesis and the consequent oxygen production diminished as well. Because of this confounding nature of DO, increasing and decreasing trends do not necessarily indicate improving or worsening water quality conditions.

Statewide, 14 (7.4%) stations had significant increasing 20-year trends in DO concentrations, while 29 (15.3%) stations demonstrated decreasing trends. Decreasing trends in dissolved oxygen do not in all cases indicate deteriorating water quality conditions. In some of the observed declining trends the dissolved oxygen appears to be moving away from supersaturated conditions, indicative of excess photosynthesis, to conditions where super saturation is not occurring (refer to Figure 2.4-5, below).

Projected estimates of the DO concentrations in 2008, using the trend analysis slope estimators, predict that one station with a significant DO trend would violate the water quality standard within the next assessment cycle. That station, on the Northwest River (5BNTW011.90) in the Dismal Swamp / Albemarle Sound sub-basin, was already listed for naturally occurring DO impairment in the 2004 Integrated 305(b) / 303(d) Report. This station may warrant additional study. Statewide, 77.2% of the trend stations showed no significant trend.

Ten-year trend analyses revealed similar proportions of increasing 7 (3.0%) *vs*. decreasing 8 (3.5%) apparent DO trends, although the total number of apparent trends identified was only about one third of that identified for the 20-year period. Of the 230 sites evaluated, 93.5%, showed no significant trend.

TOTAL NITROGEN (TN), OXIDIZED NITROGEN (NOX), and TOTAL KJELDAHL NITROGEN (TKN)

Nitrogen is an element essential to all life forms and is especially important to the growth of vegetation, including both aquatic vascular plants and algae. Although some nitrogen is required to support plant and animal life in healthy lakes, streams and estuaries, an excess of nitrogen is an indication of nutrient over-enrichment, an undesirable water quality characteristic. Nitrogen enters the waterbody from several main sources: (1) atmospheric deposition, mainly from oxides of nitrogen produced during combustion of fossil fuels, (2) domestic and industrial wastewater treatment plants, (3) urban and suburban stormwater runoff, (4) concentrated animal feeding operations (CAFO), (5) agricultural fertilization, and (6) leaching and groundwater transport from septic drain fields.

Total nitrogen (TN), as reported here, is the sum of the concentrations of ammonia/ammonium ion, nitrate, nitrite, and organic nitrogen. Oxidized nitrogen (NOX) is the sum of nitrite (NO_2^-) and nitrate (NO_3^-). Total Kjeldahl nitrogen (TKN) is the sum of ammonia nitrogen (NH_3), ammonium nitrogen (NH_4^+) and organic nitrogen. Typically the concentration of ammonia is extremely low or non-detectable.

The species of nitrogen entering Virginia's watersheds vary, based on the source. Atmospheric nitrogen entering the watershed is primarily NOX, although ammonium deposition can be a problem in localized areas. Other sources of NOX include runoff from fertilizer used on lawns, golf courses, and farms. Wastewater treatment plants also may contribute significant loads of NOX to receiving waters. NOX is readily converted into TKN and N_2 gas by plants and microbial organisms. This shift from NOX to TKN is most evident in our tidal waters, which typically contain greater concentrations of phytoplankton and higher ratios of TKN to NOX than our free-flowing streams. Significant ammonia concentrations are rarely present and, when detected, are usually associated with wastewater treatment plant final effluents or overflows, or the over-application of manure used for fertilizer. In water and in soil, environmental ammonia/ammonium is readily oxidized to NOX, which is incorporated into the biomass as TKN or released in its inert form as N_2. This facility of conversion among nitrogen species often confounds the interpretation of trends for a specific form of the element, e.g. (TKN or NOX). Consequently, trend interpretations for total nitrogen are more reliable than other nitrogen-related parameters.

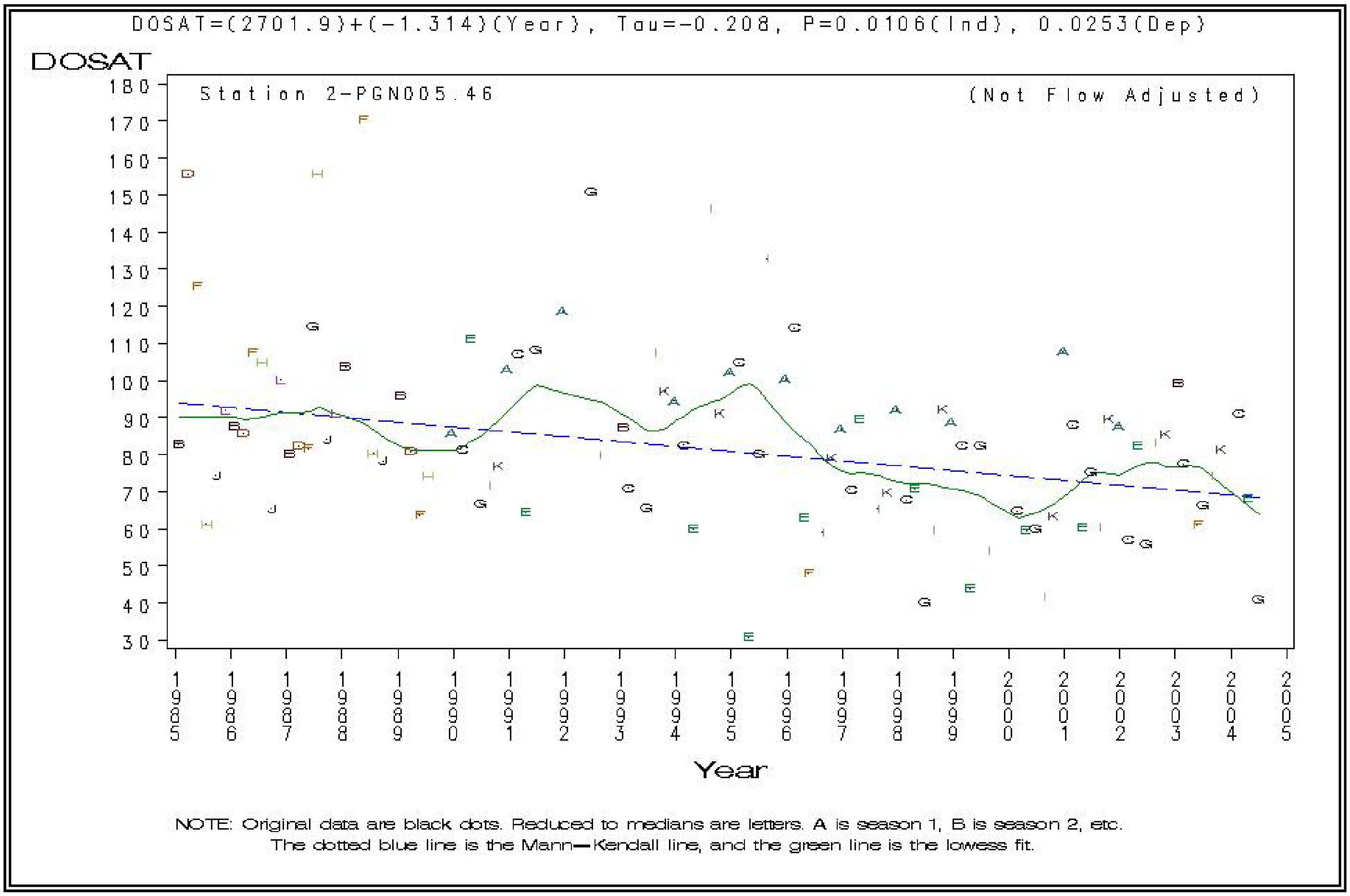

Figure 2.4-5. Dissolved Oxygen, % Saturation Trend at Station 2-PGN005.46 on the Pagan River, 1985-2004. The illustrated significant declining trend in oxygen was accompanied by significant declining trends in total nitrogen (-0.16 mg/L/yr) and total phosphorus (-0.05 mg/L/yr) concentrations. These desirable trends in nutrients may have induced consequent declines in DO.

A decrease in total nitrogen concentrations over time is considered to be an improvement in water quality. Statewide, significant long term (20-year) improvements were detected at 27 stations (16.6%), with most of the improvements occurring in the James (10 sites), Potomac/Shenandoah (9 sites), and Chowan (5 sites) basins. Ten stations (6.1%) had significant increasing total nitrogen trends; the York basin stands out with four stations exhibiting increasing concentrations in total nitrogen during the past 20 years. No significant total nitrogen trends were detected at 77.3% of the stations.

The York basin also had two (28.6%) stations exhibited increasing NOX concentrations and seven (46.7%) stations with increasing TKN. The Potomac/Shenandoah (9 sites, 25.7%) and James (15 sites, 34.9%) basins showed significant improving 20-year trends in NOX concentrations. Overall, 28 stations statewide (17.8%) had decreasing NOX concentrations, while 9 stations (5.7%) had increasing NOX concentrations.

Among the 187 sites evaluated for 10-year total nitrogen trends, twelve sites (6.4%) were identified with apparently decreasing TN trends and eight (4.3%) with apparently increasing trends. This is less than half the number of TN trends identified for the 20-year period. Ten-year oxidized nitrogen analyses revealed 17 decreasing (9.2%) and eight increasing (4.3%) trends out of 185 stations. TKN was the only nitrogen species that revealed more increasing than decreasing trends during both periods; 13 (7.1%) and 8 (4.3%), respectively, for the 10-year period and 23 (12.0%) and 18 (9.4%), respectively, for the 20-year period. Although TKN trends are more difficult to interpret that those in TN, most TKN increases appear to occur in the lower, tidal portions of major rivers (York, James, Potomac, Rappahannock) where algae blooms are seasonally present.

TOTAL PHOSPHORUS (TP)

Phosphorus, like nitrogen, is essential to all life. Phosphorus is also an important factor in the growth of plants, including aquatic vascular plants and algae. Excess phosphorus, in the presence of sufficient nitrogen and sunlight, also results in eutrophication.

In 1988 the Commonwealth of Virginia, having recognized the role of nutrient enrichment in the deteriorating water quality conditions of Chesapeake Bay, implemented a ban on the sale and use of household detergents containing phosphates. Prior to this time most of the phosphorus entering Virginia's watersheds was from treated wastewater. Following the ban, the relative contribution of phosphorus to the Bay shifted from point sources such as wastewater treatment plants, toward non-point sources such as farms, concentrated animal feeding operations, and urban stormwater runoff.

Of all the water quality parameters analyzed for trends, phosphorus is the clearest example of how the targeted and informed management of an environmental problem can have a positive result. Not all 254 trend stations had complete phosphorus data records, but statewide, 36 out of the 189 stations (19.0%) had statistically significant long-term (20-year) declines in total phosphorus concentrations. Increasing concentrations were detected at only three stations (1.6%), two in the Potomac/Shenandoah and one in the Chesapeake Bay basin. No significant trends were detected in 79.4% of the stations.

One site, on the North Fork of the Shenandoah River, is directly downstream of a single Publicly Owned Treatment Works (POTW) that treats large quantities of wastewater from local poultry processing facilities. Since 1998, there has been a general shift in the poultry processing industry from nitrogen-based cleaning and disinfecting agents to phosphorus-based agents.[10] It appears that this change may have affected phosphorus levels in the effluent of three large poultry processing plants in the North Fork Shenandoah basin. Cargill and Pilgrim's Pride facilities discharge to the North Fork Shenandoah near Timberville, and George's Chicken discharges to Stony Creek, a tributary to the North Fork of the Shenandoah. Another site with increasing total phosphorus, on Opequon Creek in the Potomac/ Shenandoah basin, is influenced by discharges from the Parkins Mill STP, which serves the rapidly growing Winchester and Frederick County area. In 2000, the Hood milk processing plant began discharging wastewater to the Parkins Mill sanitary system, significantly increasing its phosphorus load. The Parkins Mill STP is in the process of being upgraded, but its increased flow will still dominate stream flow and ambient water quality during dry periods. The influence of these POTW discharges on trend analysis results were enhanced by the extended drought and low flow conditions in the Shenandoah during the years (1998-2002), toward the end of the long-term trend analysis period.

Another site that indicated water quality deterioration (increasing concentration) in phosphorus is on Holdens Creek (7-HLD002.67) on the Eastern Shore, which receives flow from Sandy Bottom Branch, dominated by effluent from the Tyson Foods Incorporated facility (VPDES permit number VA0004049) at Temperanceville. Inspection of the trend graph indicates that phosphorus concentrations have been dropping there since 2003, which is attributed to recent improvements at the facility.

The slope estimators at those sites with statistically significant trends were used to calculate estimates of the expected phosphorus concentrations in 2008 (next assessment cycle). The results predict that the concentrations of phosphorus will be equal to or exceed the water quality screening value (TP = 0.2 mg/L) at four sites. Three of the four stations are expected to exceed acceptable phosphorus concentrations although the concentrations are significantly decreasing from the high median levels that were present early in the analysis period, Shingle Creek (2-SGL001.00) in the City of Suffolk, West Neck Creek (5BWNC001.73) and Thalia Creek (7-THA000.76) both in the City of Virginia Beach. The fourth station of concern is Holdens Creek (7-HLD002.67) mentioned above.

[10] Exemptions to the 1987 legislation banning phosphate household detergents permit the use of phosphate-based cleansers or sanitizing agents "used in dairy, beverage, or food processing equipment; [and…] products used as an industrial sanitizer, brightener, acid cleaner or metal conditioner, including phosphoric acid products or trisodium phosphate…" (Code of Virginia § 62.1-193.2. Exceptions)

Shingle Creek is listed as a 303(d) impaired water for Fecal Coliform, Dissolved Oxygen, pH, and Unknown with the following fact sheet comment: “Targeted monitoring is necessary to further delineate the extent of impairment and to characterize its causes and sources.”

The West Neck Creek station is listed as a 303(d) impaired water for Chloride with the cause being natural conditions.

Holdens Creek and Thalia Creek are already listed for bacteria impairments, with the following fact sheet statement in common: “Targeted monitoring is necessary to further delineate the extent of impairment and to characterize its causes and sources.” Other key water quality parameters, including phosphorus, should be studied during the targeted monitoring.

Of 261 stations evaluated for 10-year TP trends, 167 had sufficient records for trend analysis. Only 12 significant 10-year trends in total phosphorus were identified statewide; nine decreasing (5.4%) and three increasing (1.8%). Two of the three increasing trends correspond to North Fork Shenandoah and Opequon sites identified above. The striking difference in numbers of decreasing trends in TP between the 20-year and 10-year periods, 36 and 9 respectively, is probably because the rapid decline in phosphorus concentrations following the 1988 implementation of the phosphate detergent ban was included in the 20-year period. The more recent 10-year period began seven years after the initial ban, and subsequent improvements in phosphorus concentrations were much more subtle.

As with total suspended solids (see below), total phosphorus trends should be interpreted cautiously. In rivers where the dominant phosphorus sources are non-point (such as agricultural and suburban runoff), large proportions of the water-borne phosphorus can occur in forms bound to transported sediments. In such watersheds, total phosphorus trends can be strongly influenced by any changes in sediment transport, which is strongly affected by stream flow, even if flow is not identified as having a statistically significant trend.

ACIDITY / ALKALINITY – pH (PH)

The value of pH is expressed as a logarithmic measurement of the hydrogen ion concentration, and can be interpreted as an indicator of acidity (or alkalinity) of the water. As defined by Virginia’s Water Quality Standards, pH values lower than 6.0 (acidic), with the exemption of those occurring naturally in swamp waters, or higher than 9.0 (alkaline) are normally considered harmful to aquatic life. Except for those occurring naturally, low pH values in the Commonwealth’s surface waters are most often associated with acid drainage from mining disturbances. Declining trends in pH values may also be associated with acid rain deposition resulting from the uncontrolled combustion of fossil fuels. Elevated pH values, when they occur, are most likely the result of eutrophication.

The number of significant long-term decreasing pH trends outnumbered increasing trends by almost three to one. Twenty-three stations (12.0%) showed decreases in pH values, *versus* 6 (3.1%) with increasing values. Of 261 sites evaluated for 10-year pH trends, 31 (11.9%) had insufficient (too few data points to calculate a trend) data, while 230 stations contained sufficient data for analysis. The distribution of shorter-term, 10-year trend analysis results was similar but less disparate, with 26 decreasing (11.3%) and 20 increasing (8.7%) trends. Further special studies are needed to characterize the extent and source of the significant declines in pH. The first step will be to repeat the trend analysis for pH, including the entire period of record available for each site, and to expand the watershed station list to include all ambient stations that have sufficiently large data sets. This more detailed trend analysis is expected to be included in the 2008 integrated report. 84.9% of the stations showed no significant change in value over the 20 year record.

Use of the trend analysis slope estimator to predict the values of pH by 2008 indicated that no stations are expected to violate the water quality standard within the next assessment cycle.

TEMPERATURE (TEMP)

A proper range of water temperatures is important for sustaining healthy communities of aquatic organisms, and temperature standards have been established for “the propagation and growth of a balanced indigenous population of aquatic life.” Temperature has an influence on regulating respiration and reproductive rates of aquatic organisms, as well as determining the maximum concentration of dissolved oxygen within the ambient water column.

Among the few significant 20-year temperature trends detected, only four stations (2.0%) had increasing temperature trends and six (3.0%) had decreasing trends, while 94.9% of the stations showed no significant change in temperature. Of the stations with increasing temperatures, none are expected to exceed a water quality standard by 2008. Of the 261 sites evaluated for 10-year water temperature trends, 31 (11.9%) had insufficient (too few data points to calculate a trend) data records. Apparent shorter-term, 10-year trends in temperature were more numerous, with 20 (8.7%) increasing and 5 (2.2%) decreasing. The reason for this substantial increase in warming trends over the last ten years has not yet been explained and is of concern. 89.1% of the stations had no detectable trends in temperature.

TOTAL SUSPENDED SOLIDS (TSS)

The measurement of Total Suspended Solids (TSS) is a measure of the concentration of solid particles suspended in the water column. Although no water quality standard or screening value exists for TSS, it is still an important water quality variable. Excess TSS can transport toxic organic compounds, toxic metals and excessive phosphorus loads, and sedimentation can cause habitat destruction and benthic macroinvertebrate impairment. Excess TSS in the water column also blocks sunlight, which is necessary for photosynthesis and the propagation of submerged aquatic vegetation. Sources of excessive TSS vary, with the most significant being erosion from agricultural areas, construction sites, land clearing activities and unregulated silviculture. Other potential sources of excess TSS are urban stormwater runoff and stream bank erosion. Of all the water quality measures routinely monitored by DEQ, TSS is the most flow dependent.

The results of trend analysis indicate that significant progress has been made in the reduction of TSS concentrations. Twenty-two sites (11.2%) revealed significant decreasing 20-year trends in TSS concentrations, while only five sites (2.6%) revealed increasing 20-year TSS trends. TSS remained unchanged at 86.2% of the stations.

Of the 261 sites evaluated for 10-year TSS trends, 29 (11.1%) had insufficient (too few data points to calculate a trend) data records. The results from the analysis of 10-year TSS trends were almost identical to those for 20-year trends, with 29 (12.5%) decreasing trends and six (2.6%) increasing trends. The large number of sites with improving TSS values is most likely due to local government ordinances for the control of erosion and sediment transport. Stormwater retention, non-point source control at construction sites, and other best management practices such as improved riparian buffers and livestock exclusion have also made notable progress in reducing TSS loadings to the Commonwealth's free-running surface waters.

Interpretations of DEQ's TSS data, however, must be made cautiously and with full realization of limitations to TSS characterization that are inherent in DEQ's monitoring methods. DEQ's monitoring programs are conducted using a "fixed interval" sampling method, which is most appropriate for sampling and characterizing dissolved constituents. TSS concentrations, however, are strongly affected by streamflow. In order to fully characterize TSS as a water-quality constituent, a stream monitoring protocol would need to emphasize high-flow events.

CONCLUSIONS

Although trend analyses discussed in this chapter have been summarized on a statewide and regional (basin-by-basin) basis, the results should not be interpreted as being representative of all of the Commonwealth's water resources. The broad characterizations presented here are not intended to describe the current conditions of state waters, but rather to summarize the predominant direction of changes in water quality at primary monitoring locations over periods of ten (1995-2004) and twenty (1985-2004) years. Given that the monitoring locations where these analyses were performed are widely distributed throughout the Commonwealth's major waterways, the results do indicate a general improvement in water quality during the periods of interest.

As was pointed out earlier in this chapter, reliable trend interpretations of a number of the parameters evaluated in this study may be complicated by a variety of interacting factors. Of the nine parameters considered in these trend analyses, only four (bacteria, total nitrogen, total phosphorus and total suspended solids) are capable of demonstrating clear, easily interpreted trends without being complicated or confounded by variations in other physical, chemical or biological water quality variables. Consequently, this summary discussion will be limited to the observed patterns in these four parameters.

The statewide assessment of long-term trends indicated substantial improvement in water quality since

1985. Of the 117 long-term trends of the four key water quality variables (bacteria, nitrogen, phosphorus, and total suspended solids) that were statistically significant at the dependent-p ≤ 0.05 level, 97 individual trends (82.9% of the statistically significant trends for these four parameters) indicated improving water quality, while only 20 trends (17.1%) indicated deteriorating water quality. When considering long-term trends within individual basins, however, the York appeared to be under the greatest stress, having a greater number of deteriorating than improving water quality conditions (Tables 2.4-4 and 2.4-5). Similar results for these four parameters were evident during the most recent 10-year period; 89 improving trends (82.4%) and 19 deteriorating trends (17.6%) out of 108 trends significant at the dependent-p ≤ 0.10 level. Fewer significant trends were identified within the most recent 10-year period, even after relaxing the confidence level requirements for the shorter-term trend analyses from 95% to 90%. A statewide summary of all nine parameters, comparing the percentages of calculated trends that were statistically significant for the 20-year (1985 to present: dependent-p ≤ 0.05) and 10-year (1995 to present: dependent-p ≤ 0.10) periods, is presented in Table 2.4-8. The most notable differences between the two periods were for fecal coliform bacteria (BACT), where considerably more declining trends were identified during the most recent 10-year period, and for total phosphorus (TP), where considerably fewer declining trends were identified during the most recent period. Both of these differences were evaluated in detail in the earlier discussions of individual parameters.

	BACTERIA		DISSOLVED OXYGEN		TOTAL NITROGEN		NITROGEN OXIDIZED		TOTAL PHOSPHORUS		PH		TEMPERATURE		TOTAL KJELDAHL NITROGEN		TOTAL SUSPENDED SOLIDS	
BASIN	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
1985 to present	1.1%	6.6%	7.4%	15.3%	6.1%	16.6%	5.7%	17.8%	1.6%	19.0%	3.1%	12.0%	2.0%	3.0%	12.0%	9.4%	2.6%	11.2%
1995 to present	1.0%	19.2%	3.0%	3.5%	4.3%	6.4%	4.3%	9.2%	1.8%	5.4%	8.7%	11.3%	8.7%	2.2%	7.1%	4.3%	2.6%	12.5%

Table 2.4-8. Comparative Trend Analysis Results from Long-Term (20-Yr) and Mid-Term (10-Yr) Data Sets. Although fewer trends were significant using the shorter data set, the general pattern of improving conditions was evident, especially for the more easily interpreted core parameters of bacteria, total nitrogen, total phosphorus and total suspended solids (highlighted columns).

The increase in the number of impairments reported in recent 305(b) assessments might appear to conflict with the conclusions in the previous paragraphs. There are several reasons why the increase should not be considered an indication of water quality deterioration over time within the Commonwealth. First, the number of impairments identified in 303(d) Lists is cumulative. Newly identified impairments are added to the previous list each cycle, while delistings resulting from successful TMDL implementations and other best management practices occur more slowly. Also, many newly identified impairments result from the increasing efficiency and expanded geographic coverage of DEQ's monitoring program, as described in its Millennium 2000 Water Quality Monitoring Strategy. The rotation of monitoring stations into additional local watersheds not only expands geographic coverage, but often involves the monitoring of smaller streams that have not been assessed previously. Additional increases in numbers of impairments also may result from changes in the Water Quality Standards. For example, the lowering of the instantaneous fecal coliform bacterial standard from 1000 to 400 colonies/100mL resulted in an increase in the number of bacterial impairments reported in 2004. The recent transition from the former fecal coliform water quality standards to the recently established standards for *E. coli* and *Enterococci* bacteria conceivably could also result in the identification of additional impairments, and the forthcoming establishment of nutrient criteria for both fresh and estuarine waters will undoubtedly do so.

Earlier in this chapter, it was pointed out that an average of 82.3% of the site-parameter pairs examined failed to reveal significant 20-year water quality trends. Although this may be interpreted in a positive light, in the sense that we are 'holding our own' under the assault of growing population and developmental pressures, it is unsatisfactory for attaining our long-term goals. Tributary strategies developed for the Commonwealth's major river basins, both within and outside of the Chesapeake Bay drainage[11], require significant reductions in nutrient and suspended sediment loads that will not be accomplished by maintaining the status quo.

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[11] Commonwealth of Virginia. 2005. Chesapeake Bay Nutrient and Sediment Reduction Tributary Strategies. 85 pp.
http://www.naturalresources.virginia.gov/Initiatives/VirginiaWaterQuality/index.cfm